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Efficiency of syringe irrigation in chemomechanical root canal treatment

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ABSTRACT

Syringe irrigation is still the most shared clinical procedure for delivering endodontic irrigants. The shape and size of apical preparation should be matched to the individual morphological profile of the root canal to perform adequate cleaning. The irrigant flow beyond the needle tip seems to be influenced by the flow rate rather than the individual intra-barrel pressure developed within syringe. Proper selected size of the irrigation needle adapted to corresponding apical preparation size and the multiple maneuvers of irrigation should result in an expected cleaning efficacy. Irrigant replacement, shear stress and apical pressure are crucial cleaning factors in mutual contradiction. Presently no consensus came out to establish to whom should be forwarded the main concern.

Keywords: root canal, chemomechanical treatment, syringe irrigation

INTRODUCTION

Presently the most approached procedure of root canals irrigation in chemomechanical treatment relies on the use of a syringe and needle, followed by passive ultrasonic activation [1].

However, if for a single rooted tooth that presumes a simple anatomy of the endodontic system the common irrigation by syringe and needle might be efficient, in multi-rooted or other teeth characterized by more complex internal morphology definitely additional activation techniques of irrigant should be used [1].

Clinical efficacy of syringe irrigation is based on the positioning of irrigation needle as close as possible to the working length (WL), on the available space around the needle in the apical terminal canal and, as much as on hydrodynamic effect of flow rate of the delivered irrigant in the apical third of the root canal [1].

The efficacy of syringe irrigation relies on the needle irrigation diameter, the penetration depth toward the WL of selected needle, the size of apical preparation, and the flow rate of the irrigant [1,2].

If not the cleaning effect, the root canal irrigation is associated with secondary important outcomes such as shear stresses on canal wall, apical pressure and continuous irrigant replacement [28]. Apical preparation is pivotal in generating these outcomes [3].

Apical preparation

The high variability of tooth anatomy requires a tailored shape of the apical preparation in order to achieve the best debridement, cleaning and sealing of the root canal [4]. An extensive preparation though facilitates the most asked improved irriga-

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tion is challenging for tooth morphological integrity due to occurrence of possible dentinal cracks and post-operative pain [5-7]. To avoid the unwanted clinical outcomes the shape and size of apical preparation the mechanical apical enlargement should be matched to the individual morphological profile of the root canal [7].

Presently in current practice due to the predominantly use of nickel-titanium 4% and 6% taper rotary files for canal enlargement the form of the apical preparation implicitly reproduces the corresponding terminal file profile [4].

Nevertheless, the recommendations for the size of apical preparation are inconsistent as same favorable clinical outcomes came out in both lower (ISO 30-40) or larger size (ISO 45-80) [8,9].

The disagreement between the partisans to minimal apical preparation and those of large preparation has definitely a biological relevance since is equally imperative to avoid ledge formation, apical transportation or zipping, as well as to get improved debris removal and disinfection of the approached root canal [4,10].

Aiming the apical healing, presently the endodontists are still balancing between the unwanted clinical consequences of minimal preparation and extended apical preparation, the last one especially in retreatments in addition to the trend of improved debridement might result in periapical flare-up [10].

Apical cleaning

The most shared irrigation method used in dental settings to deliver irrigants inside the apical end of the root canals still relies on the use of a syringe and a needle. Hitherto any other method of chemomechanical treatment further than manual or rotatory instrumentation proved to be superior in achieving an improved long-term clinical efficacy [1].

Numerous studies focused on apical cleaning proved that the efficiency of manual K file ISO 30 enlargement associated with 27-G needle irrigation was similar to increased instrumentation with K file ISO 45/50 and larger diameter 25/23-G irrigation needle [4].

Likewise, same cleaning efficiency was achieved regardless the manner of preparing the apical root canal, either by K file ISO 35 or rotary NiTi files 30/06 [11].

Nevertheless, it should be stressed that is paramount for efficiency of apical cleaning to enlarge over ISO 25 at WL as the insufficient apical enlargement only up ISO 25 or less can not allow the irrigant flow to reach the demanded WL [1].

Design of irrigation needles

Commonly the irrigation needles are manufactured as open-ended or close-ended. The open-ended needles have diverse needle tip design, mainly beveled or notched and both deliver a straightforwardly flow of irrigant through their tip. The closed-ended ones have a round tip and one or more side ports or vents that let a lateral indirect outflow [12,13].

The open-ended needles are more efficient than closed-ended ones of similar size in cleaning the apical third of the root canal [12,14,15]. Conversely, they should be carefully used due to higher risk of apical extrusion [16].

Regarding the optimal positioning of the irrigation needle it was observed that the open-ended needles should be at 2-3 mm short to the WL as compared to 1 mm recommended distance for the closed-ended [13-15,17].

Also mandatory for both of them is to allow a free non-restricted movement, without wedging, into the root canal whereas delivering the irrigant in order to allow its backflow coronally [13-15,17].

Gauge of irrigation needles

Morphological the root canal is mainly curved. In straight root canals the irrigant flushing effect commonly reaches WL when the needle tip is situated at 3 mm distance. In curved root canals the flexible irrigation needles that presently range between 27-31G also allow a proper insertion short to the WL and the free flow back of irrigant delivered by syringe [1,13].

Presently the optimal insertion depth for open-ended needles is located 2-3 mm from WL as compared to closed-end ones where the recommendation is to be inserted within 1 mm short from WL [1].

It is established that a 27G irrigating needle has a good clinical efficacy as reaches the expected apical limit of penetration after K file ISO 30 instrumentation [4]. A comparable flushing outcome was also recorded after for both K file ISO 35 and tapered rotary 30/06 [8]. The minimal apical instrumentation with K file ISO 30-35 also allows the proper insertion of 30G/31G irrigation needles without binding [1].

Any apical instrumentation under K file ISO 30 impedes the canal flushing to the WL regardless the gauge and shape of irrigation needle [15] though the root canal taper seems to be less worthy concerning the irrigant access in the apical third of root canals [18].

Final apical preparation below 30 ISO master apical file and irrigation with needles with increased diameter (23G/25G) do not allow appropriate flushing [2].

Accordingly, the trend is to consider the 30G needle the clinical standard and soon to shift to the 31G irrigation needle since the former large needles 21G/25G are pretty inefficient by delivering the irrigant commonly only up to the half distance to WL [1].

When enlarging the apical canal with at least 30-40 ISO master apical file, a 27G open-ended irrigating needle placed at 3 mm from the WL is successfully cleaning the apical third of the root canal. However, for narrower root canals finer needles such as 30G or 31G are required [2].

Nevertheless, the worth of such fine safety tip side-vented irrigation needle in cleaning efficacy of debris removal should not hinder in narrower root canals the alternating agitation with a small size K file or a well-fitting gutta-percha point at WL [19,20].

A drawback of the fine safety tip side-vented irrigation needle (30G / 31G) for clinical use might be the inner salt crystals accumulation of sodium hypochlorite due to the irrigant stagnation between the lateral outlet and the closed-end tip of the needle. Hence in clinical practice might be useful to discharge them now and then [22].

The "gauge-G" system that classifies the needle size does not match to the ISO specification and can not be directly used in endodontic practice [28]. Hence, in order to minimize the risk of irrigating needle binding into the root canal should be considered a tolerance of its external diameter [21].

Depth of needle insertion

Depth of needle insertion is crucial as the cleaning effect of irrigation depends on the correlation between two diameters, inner diameter of the root canal and external diameter of the irrigation needle [22].

The same volume of irrigant (6 ml) removed significantly more bacteria (Pseudomonas fluorescens) when it was placed at 1 mm from WL than its delivery at 5 mm distance from previous apical level [23].

However excessive enlargement should be avoided. Already by using 80 ISO master apical file during syringe irrigation are generated turbulences which impede the adequate evacuation of debris and detached biofilms [2].

Obviously the irrigation dynamics, namely the penetration and flushing effect of irrigants depends on the system of irrigant delivery and its flow rate through the canal to its apical terminus. Additionally should also be correlated in any individual case with the anatomical factors of the root canal, such as size, shape, curvature and physical parameters of the irrigation needle, meaning needle tip design, external diameter as well as the depth of needle positioning from the WL [20,25].

Commonly it is thought that a previous apical enlargement to ISO size 40 allows an efficient flushing of canal terminus when the irrigation needle 27G is located at 3 mm from WL [13]. In contrast, whereas the needle tip is situated somewhat further in the apical third of the root the cleaning efficacy of irrigation depends on the needle design [13].

When using for irrigation a 27G beveled or notched needle introduced at 5 mm from the WL the irrigant, even hardly, may reach the apical limit. Conversely, in case of closed-end side-vented 27G needle the "dead irrigant zone" is evident. However, in a more apical insertion of both kind of open-end and closed-end side-vented, at 3 mm from WL, the cleaning effect was demonstrated along the entire length of the root canal [13].

Control of syringe irrigation

Syringe irrigation is pretty hard to control since its efficacy depends on multiple factors such as the volume of irrigant, duration of procedure, and flow rate associated with various gauge needles and intra-barrel pressure [24].

Presently neither the optimal amount of delivered irrigant nor the relationship between irrigant volume and proper needle gouge in clinical setting are yet agreed [24].

It has to highlight that though the fine-diameter irrigation needles (30G/31G) are recognized as more efficient in flushing, in case of their use it might be expected lower flow rates. When using irrigation needle of 25G, 27G and 30G associated with a syringe of 5 ml capacity there were reported mean flow rates (ml sec^{-1}) ranging between 0.39 (25G), 0.29 (27G) and 0.22 (30G) [24].

Despite the wide variation of irrigant flow rate recorded among practitioners the irrigant flow beyond the needle tip seems to be influenced by the flow rate rather than the individual intra-barrel pressure developed within syringe [24].

Previously to elucidate the uncertainty about the outcome of flushing effect of endodontic irrigation up to the apical terminus of root canals and to detect the dynamics of irrigant flow were conceived methods of visual survey using colored dye or radiopaque solutions [23].

Afterward were added real-time imaging of bioluminescent bacteria and digital captured stereomicroscopic images techniques, which improved the collected data but still did not offered sufficient understanding about the flow pattern of irrigant delivered by syringe in the root canal [2,22,23].

However, more advanced information was finally achieved by using computational fluid dynamics (CFD) models as opened the opportunity to find out the effect of different irrigation needle on the irrigant flow pattern developed during manual syringe delivery into the root canal [13,22,25].

Flow pattern of irrigant

According to the CFD appraisal it seems that the inlet needle velocity is in charge with the flow pattern of syringe delivered irrigant within the root canal [22].

The resulted jet of irrigant in side-vented and double side-vented needles [22,26] is sent toward the apical constriction with an oblique angle of rather 30o and follows a curved pathway around the closed-end tip of the needle. This particular behavior restricts a straight direction toward the apex, before to end its back way to the canal orifice located in pulp chamber [22].

The laminar flow running into the irrigating needle lumen comes up to the turbulent flow generated close to the side-vent outlet and around the needle tip. This kind of flow pattern contributes to beneficial mixing inside the root canal of the previously existent irrigant with a fresh one. Accordingly, the repeated irrigant replacement with syringe much involves the flow rate and enhances the cleaning efficacy of endodontic irrigation [22,25].

Beyond the needle outlet the fluid velocity decreased due to the rather rapid downstream flow expansion [22]. The flow pattern, which is considerably influenced by flow rate, has a definite clinical relevance as shows a flushing effect limited 1 to 1.5 mm apically to the safety tip of side-vented irrigation needle, regardless the highest outlet velocity of the endodontic irrigant [22].

Beyond 2-3 mm from the tip of a beveled or notched needle it was observed an apical area untouched by irrigation, which is a so called “dead irrigant zone” [21,25].

The flow pattern of irrigating jet in closed-end side-vented is more laterally oriented to the root canal wall. In double side-vented the flow out from proximal outlet measures 93.5% from global outflow delivered. Practically the outflow of the distal outlet has no clinical cleaning efficacy [16].

The multi-vented needles have 3 pairs of outlets. The most proximal outlets pair is in charge with 73% of the global flow. The second pair delivers 25% and the last one, the most distal located, only 2% of the total irrigation flow [16]. Extremely reduced flow velocities were recorded in the area between needle tip and WL location [16].

Flow velocity of irrigant

The flat or beveled open-ended needles deliver similar high velocity irrigation flows as compared to notched open-ended where the flow velocity is somewhat diminished [16].

At the side-vented irrigation needles the highest irrigant velocities developed in the proximity of needle outlet and their magnitude was in direct relationship with the initial outlet value [17].

Particularly in closed-end side-vented needle was recorded an irrigant velocity of 0.1 m/s directed on the canal wall compared with much lower 0.044 m/s velocity measured on the opposite wall of the root canal. The clinical significance of the irrigant flow velocity underlines the direct relationship with the subsequent cleaning ability [25].

Commonly the irrigant velocities running on canal walls are pretty low. When irrigating with closed-end side-vented needle at 3 mm from WL the flow velocity insignificantly decreased on the opposite canal wall, compared to the wall facing the needle outlet. Reducing the insertion depth of same closed-end side-vented needle at 5 mm to WL no differences of flow rate velocity were recorded on both canal walls [21].

A flow rate of 0.02-0.26 ml sec^{-1} achieves only a minor replacement of the irrigant in the root canal, less than 1 mm apically from safety tip of side-vented irrigation needle [21]. Accordingly, should be emphasized the positioning of needle tip within 1 mm from recommended apical treatment limit [27].

Increasing the outlet velocity to a flow rate of 0.53-0.79 ml sec^{-1}, possibly associated with a higher turbulence, facilitates the extension of irrigant replacement to 1-1.5 mm apically to the tip of same kind of irrigation needle [17].

However, it should be highlighted that unless the flow rates of 0.02-0.26 ml sec^{-1} that are clinically usual in root canal irrigation, the higher flow rates of 0.53-0.79 ml sec^{-1} though their advantage to ensure an extended apical spread of irrigant of 0.5 mm are seldom met in practice [22,24].

Accordingly, though an increased inlet velocity result in more dynamic substitute of irrigant in root canal, actually its cleaning efficiency depends rather on the insertion depth of safety needles related to WL [17].

In the very proximity of the needle outlet of side-vented irrigation needles the irrigant has low velocities and follows a reverse path toward the apical area of the root canal [17].

In the middle and cervical area of the root canal the irrigant flow has a lower velocity and expresses laminar pattern without any turbulences despite the magnitude of initial inlet velocity and roughness of root canal wall in the coronal two thirds [22,28].

The debridement shear stresses

The shear stress on the canal wall had alike pattern for both kind of needle design, open end and closed side-vented, as well as their maximal value of 1000 N m-2 recorded in 25/06 apically enlarged root canals. However, it is noteworthy to stress the indirect relationship observed between the shear stress and apical preparation as the shear stress decreased in higher size apical preparation [3].

Actually, an oversized enlargement reduces the debridement usefulness of irrigation [3]. However, a proper selected size of the irrigation needle adapted to corresponding apical preparation size and the multiple maneuvers of irrigation might result in an expected cleaning efficacy [3].

In contrast, a direct relationship was obvious for both irrigating needles between the root canal area exposed to the shear stress and the size of apical preparation. In flat open-end needles the maximal shear stress was situated apical to the needle tip whereas in the closed-end side-vented needles was located on the canal wall facing the lateral needle outlet [3].

The open-end needles developed on the canal wall comparable shear stresses. However beveled and notched designs did not record the highest values on the canal wall toward their outlets were oriented [26].

Concerning the closed-end needles, both single side-vented outlet and proximal outlet in double side-vented, created shear stresses on the canal wall oriented to the outlets. In the multi-vented needles was recorded the maximal shear stress concentrated on a restricted area of canal walls facing the outlets [26].

The debridement outcome of each irrigation needle depends primarily on the shear stress they generate on the canal wall enabling the detachment of dentin debris, pulp tissue remnants, smear layer and bacterial biofilms, and their subsequent evacuation from the root canal [26].

However, though both synchronic approaches of chemomechanical treatment are involved in the debridement and removal of biofilms from root canals in vitro the flow rate of sodium hypochlorite irrigation proved to be more in charge with bacterial biofilms removal than its antimicrobial activity [29].

It should be highlighted the unidirectional functioning of both side-vented and double side-vented, which achieve the maximal irrigating shear stress on the wall facing their active outlets (proximal outlet in double side-vented) [26].

The multi-vented needle, typically used in clinical practice by negative pressure system of irrigation, is considered the safest to avoid the apical extrusion. However, it should not be the gold thumb recommendation for syringe irrigation, as it necessitates a not so easy to achieve extremely closed positioning to WL and does not provide the needed shear stress for proper canal debridement on the sufficient spread area of canal wall [26].

Overall, regardless of irrigating needle design, the highest shear forces appeared in the apical third of the root canals, which is extremely beneficial to the debris removal and canal disinfection [26].

Irrigant replacement from apical preparation

Commonly the practitioners' trend is to increase the apical preparation size in order to facilitate an enhanced debridement of debris and improve the irrigant replacement [3].

Irrigant penetration up to WL is chiefly reliant on adequate size and taper of apical enlargement and positioning of irrigation needle to the root canal terminus [2,3].

According to CFD simulation of syringe irrigation, both design types of irrigating needles, flat open-end or closed-end side-vented provide an unsteady irrigant flow [3].

As much as the apical preparation size increases, the apically flow jet released by flat-needles expands further to WL resulting in a more effective removal of chemically used irrigant (sodium hypochlorite), whereas in case of closed-end side-vented needles it was found an increase of various size vortices spreaded in diverse appicaly located positions [3,29].

However, in vitro it was proved that a flow rate of 0.17 ml/s by using sodium hypochlorite is more efficient than its clinical concentration to achieve the removal of bacterial biofilms [29].

Regardless the design of open-end irrigating needle, flat or beveled, the irrigant flow is able to reach the WL when the apical enlargement is instrumented to ISO size 35, 45 or 55 [2].

Irrigant replacement depends on the available space in the canal lumen around the irrigating needle. The narrowest space is located in root canal at the maximum depth of needle tip placement. Though an increase of enlargement should improve the irrigant replacement, some other irrigation related factors, such as flux velocity and shear stress would decrease the outcome quality of endodontic treatment [3].

Irrigant replacement in apical third of the root canal was improved in spite of the needle type and was considered clinically noteworthy when the flux velocity was over 0.1 m s^{-1} [3].

Starting from 35/06 and up to 55/06 apical preparations, the flat open-end needles provided a higher irrigant removal than closed-end side-vented ones. By comparison, in 25/06 apical preparation the closed-end side-vented needles properly removed the irrigant only 0.75 mm further from their tip. Even in 55/06 preparation the irrigant removal did not achieve more than 1.5 mm apically [3].

However, despite the apical preparation size and type of irrigating needle, the reverse coronal flow succeeded the complete replacement of irrigant from the root canal [3].

In case of unwanted binding of closed-end side-vented irrigation needle the flow is allowed only coronally whereas between the needle tip and WL the irrigant replacement is annulated. Quite the reverse in case of flat open-end needle when the irrigant blocked in the apical area can not be evacuated but forced to provoke an apical extrusion [3].

The sole hope to avoid an endodontic mishap resides in existence of an oval cross-section of the root canal at the binding location, which would allow the coronal displacement of the irrigant [3].

A clinical and common recommendation for the optimal irrigant replacement in the apical third of root canal would be the insertion depth of irrigant needle. Unlike the closed-end side-vented irrigation needles that may be positioned within 1 mm short of WL, the flat open-end needles should be inserted in 35/06 apically enlarged canals at 2-3 mm short of WL to avoid the apical extrusion [3].

Apical pressure

Indirect relationship was established for both irrigating needle designs between developed apical pressure and apical preparation size but in quadratic ratio, since whilst as much as the size of apical preparation increased the apical pressure lowered [3].

The maximal apical pressure of 49.3 ± 1.3 kPa was generated by flat open-end needles in a 25/06 enlarged root canal, whereas the apical pressure developed by closed-end side-vented needles was definitely lower, namely 32.1 ± 3.2 kPa [3].

A beveled open-end irrigation needle develops an apical pressure with 7% lower than a notched open-end irrigation one of similar gauge. By comparing the design of apical end, it was observed that the irrigation with side-vent needles achieved a 17%-19% reduction in apical pressure versus open-end ones [13].

Moreover, by using same gauge side-vented needles, the closed-end ones reduce to 2.5-3 fold the apical pressure compared to a particular designed open end side-vented irrigation needle [13].

Regardless the needle design open-end (beveled or notched) and closed-end (side-vented) the irrigant pressure was higher at 3 mm from WL compared with 5 mm from WL.

However, the difference is significant. At 3 mm were recorded 1707 Pa for open-end versus 529 Pa for closed-end side-vented needles. Same dissimilarities were noted at 5 mm, 1085 Pa for open-end, respectively 256 Pa for closed-end side-vented needles [13].

Anyhow the clinical demand of irrigating the apical area at lower pressure by using irrigation needles of adequate size and design should not impede to achieve perfect cleaned canal walls [13].

Small gauge irrigation side-vented needles 30G or 31G placed 1 mm short of WL in case of controlled flow rate may be used without the risk of extrusion as the apical pressure they develop does not exceeds the back-pressure from periapical tissue [22]. However, the irrigant delivery should be carefully controlled as the pressure developed on the apical wall might reach 600 Pa [25].

Altogether, the irrigant replacement, shear stress and apical pressure are crucial cleaning factors in mutual contradiction. Presently no consensus came out to establish to whom should be forwarded the main concern [3].

CONCLUSIONS

The flat or beveled open-ended needles used during syringe irrigation deliver similar high velocity irrigation flows. The side-vented irrigation needles develop the highest irrigant velocities in the proximity of needle outlet and their value is directly related to the initial outlet value. Direct relationship was obvious for both open-end and closed-end irrigating needles between the root canal area exposed to the shear stress and the size of apical preparation. K file ISO 30-35 allow minimal apical instrumentation with the proper insertion of 30G/31G irrigating needles without binding. The trend is to consider the 30G needle as clinical standard and soon to shift even to the 31G irrigating needle.

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